Monograph:

Longo, Francesco orcid.org/0000-0002-1833-7328, Siciliani, Luigi orcid.org/0000-0003-1739-7289, Gravelle, Hugh Stanley Emrys orcid.org/0000-0002-7753-4233 et al. (1 more author) (2017) Do hospitals respond to rivals' quality and efficiency? : A spatial econometrics approach. Discussion Paper. CHE Research Paper . Centre for Health Economics, University of York , York, UK.

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Do Hospitals Respond To Rivals' Quality And Efficiency? A Spatial Econometrics Approach

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CHE Research Paper 144

Do hospitals respond to rivals' quality and efficiency? a spatial econometrics approach

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March 2017

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Acknowledgements

Hugh Gravelle, Rita Santos and Luigi Siciliani were funded by a grant from the Department of Health to the Policy Research Unit in the Economics of Health and Social Care System (Ref 103/0001). Rita Santos was also funded by an NIHR Doctoral Research Fellowship (DRF-2014-07-055). Francesco Longo was funded by the Economic and Social Research Council (grant number ES/J500215/1). The views expressed are those of the authors and not necessarily those of the funders. The authors have no conflict of interest to declare.

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Abstract

We investigate whether hospitals in the English National Health Service increase their quality (mortality, emergency readmissions, patient reported outcome, and patient satisfaction) or efficiency (bed occupancy rate, cancelled operations, and cost indicators) in response to an increase in quality or efficiency of neighbouring hospitals. We estimate spatial cross-sectional and panel data models, including spatial cross-sectional instrumental variables. Hospitals generally do not respond to neighbours' quality and efficiency. This suggests the absence of spillovers across hospitals in quality and efficiency dimensions and has policy implications, for example, in relation to allowing hospital mergers.

JEL Classification: C21, C23, I11, L3, L11
Keywords: quality, efficiency, hospitals, competition, spatial econometrics

1. Introduction

Quality and efficiency are fundamental goals for policymakers in the hospital sector. In the presence of fixed prices, policymakers have argued that competition policies may induce hospitals to compete on quality to attract patients, and to enhance efficiency (Gaynor, 2007).

A number of studies have investigated the effect of competition on quality and efficiency in the US, the United Kingdom, and other OECD countries with mixed results (section 1.1). The traditional approach involves relating quality and efficiency to a measure of market structure (e.g. Herfindahl index). In this study, we use an alternative approach and examine hospitals' strategic interactions. We investigate whether hospitals respond to changes in rivals' quality and efficiency, i.e. whether quality and efficiency are strategic complements or strategic substitutes in the sense that an increase in rivals' quality (efficiency) induces a hospital to increase or reduce its quality (efficiency).

The strategic relationship amongst neighbouring hospitals is important, for example, in relation to hospital mergers. Brekke et al. (2016) provide a theoretical analysis on hospital mergers and their effect on quality and efficiency. They show that if two hospitals merge these will reduce quality. The merger will also reduce quality in non-merging rival hospitals if qualities are complements. Merging hospitals, moreover, are likely to increase efficiency. Non-merging rival hospitals will increase efficiency if efficiencies are strategic complements.

We consider both clinical and non-clinical (e.g. amenities) dimensions of quality. Hospital level of clinical measures are increasingly available in the public domain (e.g. through websites) as part of patient choice policies. We measure clinical quality through risk-adjusted overall mortality and readmission rates, and mortality rates for high-volume conditions such as hip fracture and stroke. Mortality and readmissions rates do not however capture health gains for the vast majority of patients who do not die or are readmitted as an emergency. We therefore also measure health gains for hip replacement, a common elective procedure, based on patients-reported outcomes (PROMs). We capture non-clinical dimensions of patients' experience using patient satisfaction with overall hospital experience, hospital cleanliness, and the extent to which clinicians involved the patients in the treatment decision. We measure hospital efficiency through indicators for bed occupancy, cancelled elective operations, and cost indices for overall hospital activity, elective and non-elective activity, and for hip replacement.

We first test for spatial dependence across these quality and efficiency indicators by global Moran's I test. We find evidence of positive spatial dependence for several but not all quality and efficiency indicators. We then estimate spatial cross-sectional models by quasi-maximum likelihood (ML) controlling for observable determinants of quality and efficiency. To control for unobserved time-invariant determinants of quality and efficiency, we estimate spatial panel models. Finally, we adopt two spatial cross-sectional instrumental variable (IV) approaches. In all models, our key coefficient of interest is the spatial lag of the dependent variable. A positive estimate implies strategic complementarity in quality or efficiency. Our key finding is that cross-sectional and panel data estimates of the spatial lag mostly suggest the absence of strategic interaction across rival hospitals in quality and efficiency.

Sections 1.1 and 1.2 review the literature and the institutional background. Section 2 sketches a theoretical model. Section 3 outlines the empirical strategy. Section 4 describes the data. Section 5 discusses the results, and section 6 concludes.

1.1. Related literature

Our study relates to the literature on hospital competition and, more broadly, to spatial econometrics applications in health economics. Early studies focus on the relationship between hospital competition and efficiency in the US. They show that non-price competition combined with a cost-based reimbursement system may lead to overprovision of hospital services (e.g. Joskow, 1980, Robinson and Luft, 1985). Later studies find a beneficial effect of price competition on costs (e.g. Zwanziger and Melnick, 1988, Bamezai et al., 1999). Other studies focus on the impact of hospital competition on quality, providing mixed results. They find that competition improves (Kessler and McClellan, 2000, Kessler and Geppert, 2005), decreases (Gowrisankaran and Town, 2003) or is not associated (Mukamel et al., 2001) with clinical quality as measured by mortality.

Studies that analyse the effect of hospital competition on quality and efficiency in the UK also have mixed results. Some suggest that competition increases (Cooper et al., 2012, Gaynor et al., 2013) or is not associated with efficiency (Söderlund et al., 1997). Other studies find either negative (Propper et al., 2004, Propper et al., 2008), positive (Cooper et al., 2011, Gaynor et al., 2013, Bloom et al., 2015), or mixed impact of competition on quality (Gravelle et al., 2014a).

This study builds on the spatial approach proposed by Mobley (2003) and Mobley et al. (2009). These authors focus on strategic complementarity in prices, rather than quality, within the US context where hospital prices are not fixed. Similarly, Choné et al. (2014) study strategic complementarity of GPs' prices in France using a spatial IV approach. Gravelle et al. (2014b) use a cross section of English data and find that seven out of sixteen clinical and patient-reported quality dimensions are strategic complements.

We improve on previous spatial econometric papers in three ways: first, we employ efficiency measures in addition to quality; second, we employ panel data to control for unobserved time-invariant heterogeneity through hospital fixed effects; third, we address potential endogeneity owing to other sources of unobserved factors through two IV approaches.

Our study contributes to the small literature on spatial econometrics applications in health economics. For instance, Moscone et al. (2007) study spatial spillovers in mental health expenditure in England and find that neighbouring mental health authorities interact in their expenditure decisions. Gaughan et al. (2015) test spillover effects on delayed discharges and find that more care home beds and younger patients in nearby local authorities reduce delayed discharge. Moscone and Tosetti (2014) provide a comprehensive review of spatial econometrics applications in health economics.

1.2. Institutional background

The English National Health Service (NHS) is universal, tax financed, and free at the point of use. The Department of Health distributes capitated funding to around 150 local health authorities which use it to pay for secondary health care provided to NHS patients by public and private hospitals. Public hospitals are run by NHS Trusts or NHS Foundation Trusts, the latter having greater financial autonomy. Some NHS hospital trusts are teaching trusts providing research and teaching, and some are specialist trusts focusing on a limited range of conditions or client groups.

Hospitals are mainly funded through a prospective payment system, the National Tariff Payment System. This is based on Healthcare Resource Groups (HRGs), a patient classification system similar to the American Diagnosis-Related Group or DRG. The HRGs categorise patients into homogeneous groups depending on diagnoses, procedures, and some patient characteristics. A fixed tariff is calculated for each HRG group as its national cost averaged across providers but with adjustments for individual hospitals to reflect exogenous variations in input prices and the higher costs of specialised care (Department of Health, 2013).

Under such a fixed-price regime, hospital competition has been encouraged by allowing elective patients to choose where to be treated. The 2006 'Patient Choice' reform initially allowed patients to choose amongst four or five providers, with the choice extended to any qualified provider from 2008 (Department of Health, 2009). Patients' choice is facilitated through the website 'NHS Choices', which provides information on hospitals' performance (e.g. mortality, waiting times).

2. Theoretical model

We sketch a simple two provider model of quality competition and cost reducing effort. Hospital *i* has demand function $D_i\left(q_i, q_j\right)$ which is increasing in own quality and decreasing in the quality of hospital *j*. The objective function of hospital *i* is:

$$U_i = \left[p - c_i\left(q_i, e_i; \theta_i\right)\right] D_i\left(q_i, q_j; \theta_i\right) - G_i\left(q_i, e_i; \theta_i\right) \tag{1}$$

where *p* is the fixed price per treatment that the hospital receives from a third-party payer. $c_i\left(q_i, e_i\right)$ and $G_i\left(q_i, e_i\right)$ are variable and fixed treatment costs, respectively, which are increasing in quality and decreasing in cost-containment effort or efficiency e_i. We assume that quality and effort are substitutes in fixed costs, i.e. $G_{i q_i e_i}\left(q_i, e_i\right) > 0$, since both are types of managerial effort. To keep computations simple, we assume that quality and efficiency are instead independent in variable costs, i.e. $c_{i q_i e_i}\left(q_i, e_i\right) = 0$. θ_i is a vector of shift parameters (such as local input prices, population demographics, and morbidity). The subscripts q_i and e_i indicate the partial derivative with respect to these choice variables.

Hospital *i* chooses quality and efficiency to satisfy:

$$U_{iq_i} = \left[p - c_i\left(q_i, e_i; \theta_i\right)\right] D_{iq_i}(q_i, q_j; \theta_i) - c_{iq_i}\left(q_i, e_i; \theta_i\right) D_i(q_i, q_j; \theta_i) - G_{iq_i}\left(q_i, e_i; \theta_i\right) = 0 \tag{2}$$

$$U_{ie_i} = -c_{ie_i}\left(q_i, e_i; \theta_i\right) D_i\left(q_i, q_j; \theta_i\right) - G_{ie_i}\left(q_i, e_i; \theta_i\right) = 0 \tag{3}$$

where $D_{iq_i} > 0$, $c_{iq_i} > 0$, and $G_{iq_i} > 0$. With strictly concave utility functions these conditions are also sufficient. Note that the price must exceed the marginal cost of treating additional patients if the hospital is to be induced to provide positive quality. The optimal quality is determined such that the marginal profit from higher additional demand is equal to the marginal cost of quality. The optimal level of efficiency (cost-containment effort) is such that the marginal benefit from lower costs and higher profits are equal to the marginal disutility from efficiency.

The first order conditions (2) and (3) define the reaction functions for hospital *i*'s choice of quality and efficiency as functions of the choice of quality by hospital *j*:

$$q_i = q_i^R(q_j; \theta_i) \tag{4}$$

$$e_i = e_i^R(q_j; \theta_i). \tag{5}$$

Since neither of the first order conditions depends on the efficiency of hospital *j*, it is apparent that quality and efficiency of hospital *i* are strategically independent of the efficiency of hospital *j*.

Totally differentiating the first order conditions we obtain:

$$\frac{\partial q_i^R}{\partial q_j} = \left\{ -U_{iq_iq_j} U_{ie_ie_i} + U_{ie_iq_j} U_{iq_ie_i} \right\} \Delta^{-1} =$$

$$= \left\{ -[\underbrace{(p-c_i)}_{+} \underset{?}{D_{iq_iq_j}} - \underset{+}{c_{iq_i}} \underset{-}{D_{iq_j}}] \underset{-}{U_{ie_ie_i}} - \underset{-}{c_{ie_i}} \underset{-}{D_{iq_j}} \underset{+}{U_{iq_ie_i}} \right\} \Delta^{-1} \qquad (6)$$

where $\Delta = U_{iq_iq_i} U_{ie_ie_i} - U_{iq_ie_i}{}^2 > 0$ by the concavity of the objective function. The square bracketed term in (6) is the direct effect of the rival's quality on the marginal profit from higher quality. It is not obvious whether an increase in rival's quality reduces or increases the marginal gain in patient numbers from higher quality. Suppose for simplicity that $D_{iq_iq_j}$ is zero. The second part of the square bracketed term is the reduction in the variable cost because the increase in rival's quality reduces demand and so the marginal cost of output of hospital *i*, which then responds by increasing quality. However, the second term in the curly bracket shows that the lower demand also reduces incentives to contain costs (indirect effect) and so variable cost may increase, making increases in quality to attract additional patients less profitable.

3. Methods

We test whether hospitals' quality or efficiency responds to the quality or efficiency of their rivals using the following function:

$$y_i = f_i\left(y_{-i}, X_i, \varepsilon_i\right) \tag{7}$$

where y_i is the quality or efficiency of hospital *i* ($=1,\ldots,I$); y_{-i} is the quality or efficiency of hospital *i*'s rivals; X_i is a vector of covariates including demand shifters (e.g. population density, proportion of elderly individuals), supply shifters (e.g. number of managers, proportion of consultants), and hospital type (e.g. foundation trusts, teaching hospitals); and ε_i is the error term. From (7), we specify a cross-sectional spatial lag model:

$$y_i = \rho \sum\nolimits_j w_{ij} y_j + \beta' X_i + \varepsilon_i \tag{8}$$

where y_j is the quality or efficiency of hospital *i*'s rival *j* ($=1,\ldots,I \neq i$), w_{ij} is a weight related to the spatial relationship between hospital *i* and *j*, and X_i includes the intercept. In matrix form:

$$Y = \rho WY + X\beta + \varepsilon \tag{9}$$

where *W* is the spatial weight matrix composed of the elements w_{ij}. The spatial weights are generated from the inverse distance function:

$$w_{ij} = \begin{cases} 0 & \text{if} \quad i = j \\ d_{ij}^{-1} & \text{if} \quad d_{ij} \leq 30 \text{ km and } i \neq j \\ 0 & \text{if} \quad d_{ij} > 30 \text{ km and } i \neq j \end{cases} \tag{10}$$

where d_{ij} is the straight line distance between hospital *i* and *j*. We assume, as in recent literature, that 30 km is the radius within which hospitals compete (Gaynor et al., 2012, Bloom et al., 2015). Hospitals that are further within a 30 km radius are given a lower weight, and hospitals that are further than 30 km are given a weight of zero. The weight matrix *W* is row standardised, i.e. the elements of each row sum to one. WY is therefore a weighted average of the rivals' quality or efficiency.

The key coefficient is ρ. If $\rho > 0$ quality (efficiency) increases in response to an increase in rivals' quality (efficiency). Spatial correlation can be due to strategic interactions between providers but also to two additional categories of factors. First, unobserved characteristics common across rival hospitals may affect quality in a given area. For instance, rival hospitals with appealing neighbourhoods are more likely to attract and employ skilled doctors and managers, and provide similar quality. Second, a hospital's quality may vary with characteristics, either observed or unobserved, of rival hospitals. For instance, a hospital's quality may increase if there is a high proportion of foundation trusts amongst its rivals which enhances competition. If we fail to account for these factors, spatial correlation will be spurious. There is an analogy between our spatial approach and the peer-effects literature, which refers to the two possible sources of bias as respectively "*correlated effects*" and "*contextual effects*", and the general identification issue as the "*reflection problem*" (Manski, 1993).

To control for time-invariant unobserved factors, we estimate a spatial panel model:

$$y_{it} = \rho \sum_j w_{ij} y_{jt} + \beta' X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{11}$$

where $t = 1, ..., T$, α_i captures unobserved time-invariant hospital heterogeneity, and γ_t is a time fixed effect.

We conduct three separate sensitivity checks on regressions (8) and (11). First, we test whether disturbances are spatially correlated using a spatial autocorrelation (SAC) regression, which models spatial correlation in the error term ($\varepsilon_{i(t)} = \lambda \sum_j w_{ij} \varepsilon_{j(t)} + \xi_{i(t)}$). Second, following the theory in section 2, we test whether a hospital's quality (efficiency) responds to rivals' efficiency (quality) by adding a spatially lagged efficiency (quality) measure to the main regressions. Finally, we re-estimate our primary regressions extending the radius within which hospitals compete to 60 km or 90 km.

We estimate spatial cross-sectional models by ML and spatial panel models by fixed effects (FE) and random effects (RE) ML.[1] The ML estimator is biased in the presence of unobserved *correlated* and *contextual effects*. Although controlling for unobserved time-invariant heterogeneity α_i may alleviate the problem, the key coefficient $\hat{\rho}$ may still not be identified if there are unobserved time-varying factors affecting the patient case-mix.

As a further sensitivity check, we estimate (8) through two spatial IV approaches. The first IV approach is a two-stage least squares (2SLS) estimator that instruments WY with its 3-year lagged value (WY_{t-3}).

The second IV approach consists of a 2SLS estimator that uses a spatially lagged covariate WZ to instrument WY , where Z is a single covariate in the matrix of covariates X . This approach is inspired by the generalised spatial two-stage least squares estimator (Kelejian and Prucha, 1998, 1999).

[1] We use the Stata user-written command spreg to estimate cross-sectional models (Drukker et al., 2015), and xsmle to estimate panel models (Belotti et al., 2014).

4. Data

We have eight quality indicators and six efficiency indicators measured at hospital trust level.[2] All measures are from 2010-11 to 2013-14, except for the readmission rate which is from 2008-09 and 2011-12.

4.1 Quality indicators

The risk-adjusted Summary Hospital-level Mortality Indicator (SHMI) is the ratio of the actual number of deaths from all causes in hospital or within 30 days of discharge to the number of deaths expected given the characteristics of patients. We also use risk-adjusted mortality rates for two emergency conditions (hip fracture and stroke), and risk-adjusted emergency readmissions for all conditions.

We collect risk-adjusted average health change for patients who had a hip replacement from PROMs (patient reported outcome measures) data. On the basis of the EQ-5D questionnaire (Brooks, 1996, Brooks et al., 2005), the change in a patient's health is calculated as difference between the self-assessed health status of elective patients before and six months after their surgery. Clinical quality indicators and PROMs are available from the health and social care information centre (HSCIC).[3]

We use three patient satisfaction indicators for overall experience, hospital cleanliness, and involvement in treatment decisions. Patients were asked to rate their hospital experience on a scale between 0 and 100, whereas 0 indicates extreme dissatisfaction and 100 complete satisfaction. The indicators are obtained by averaging the patient rates across hospitals and they are risk-adjusted using patients' gender, age, ethnic group, and admission method (elective or emergency). They are available from the annual NHS Inpatient Surveys conducted for the Care Quality Commission.

4.2 Efficiency indicators

The bed occupancy rate is the ratio of occupied to available hospital beds (e.g. Zuckerman et al., 1994). We measure the rate of cancelled elective operations dividing the number of cancelled elective operations for non-clinical reasons by the number of elective admissions (Rumbold et al., 2015).

The reference cost index (RCI) compares a hospital's total costs with the national average total costs for the same HRG groups. A RCI greater than 100 indicates higher than average costs. We also use the RCI for elective and non-elective activity, and for hip replacement.

4.3 Explanatory variables

Our key regressor is the spatial lag of the dependent variable *WY*. Our control variables include demand and supply shifters. Demand shifters comprise: demographic variables such as *population density* and *proportion of elderly individuals* (65 and over), which we calculate using annual mid-year population estimates; economic deprivation measures such as *proportion of individuals employed or looking for a job*, *proportion of individuals with a degree*, and *proportion of households with property house*; and a measure of population health such as the *proportion of individuals in good or very good health*. Population deprivation and health measures are computed using 2011 Census data for all LSOAs within a 15 km radius.[4]

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[2] Detailed definitions of the quality and efficiency indicators are included in the appendix (Table A1 and Table A2).

[3] The SHMI is adjusted for gender, age, admission method, year index, Charlson comorbidity index, and diagnosis. Hip fracture and stroke mortality are adjusted for gender and age. The emergency readmission rate is adjusted for gender, age, admission method, diagnosis, and procedure. The health change after hip replacement is adjusted for patient characteristics (e.g. gender, age, ethnics), initial health status, self-assessed health status, economic deprivation, comorbidity, procedure, and post-operative length of stay.

[4] LSOAs (Lower Layer Super Output Areas) have on average 1,500 inhabitants and a minimum of 1,000.

Supply shifters include: the *number of managers*, the *proportion of junior doctors in training*, the *proportion of consultants*, and the *number of beds*.[5] Information on hospital staff is collected from the HSCIC, whilst NHS statistics provide the number of beds.[6] Finally, we control for type of hospital**:** *foundation trust*, *teaching hospital*, and *specialist hospital*.

4.4 Instruments

The instrument for our first IV approach is WY_{t-3}. It is assumed to be exogenous because: rival hospitals' quality (efficiency) with a lag of three years is unlikely to be correlated with contemporaneous unobserved factors that may affect a hospital's quality (e.g. unmeasured comorbidities). It is relevant because persistence in hospital quality (efficiency) allows for correlation between past and current rival's quality (efficiency).

Valid instruments for the second IV approach are: the (spatially) *lagged proportion of consultants* for lagged SHMI; the *lagged proportion of junior doctors in training* for lagged emergency readmission rate, all *lagged patient satisfaction indicators*, *lagged RCI*, and *lagged elective* and *non-elective RCI*; and the *lagged number of managers* for lagged bed occupancy rate and lagged rate of cancelled elective operations. Rivals' supply shifters are assumed to be uncorrelated with the error term. For example, the rivals' number of managers is unlikely to be correlated with a hospital's unobserved patient case-mix, and it is also unlikely to directly determine a hospital's quality.[7] In principle, we can expect lagged supply shifters to be also relevant (i.e. correlated with lagged quality) if supply shifters affect hospital quality. For example, if a hospital's proportion of consultants is associated with a hospital's quality we can expect some correlation between the rivals' proportion of consultants and rivals' quality.

4.5 Sample

Table I provides descriptive statistics. The number of hospital trusts varies between 106 (for hip fracture mortality rate) and 142 (for emergency readmission rate) across indicators. The sample size for each indicator is determined by the number of hospitals with at least one rival, and is constant over time because we use a balanced panel. Hospitals with no providers within a radius of 30 km (i.e. monopolists) are excluded from the sample because, by construction, they do not compete. Considering the overall patient satisfaction's sample 13% of hospitals are monopolists. 23% are exposed to low competition with one or two rivals. 38% are located in areas with three to nine rivals, and 26% have more than nine rivals (up to a maximum of 25 rivals).

4.6 Descriptive statistics

The SHMI is on average 100 by construction. Mean hip fracture mortality rate is 7.2% and mean stroke mortality is 17.4%. The mean emergency readmission rate is 11.1%. On average, patients undergoing hip replacement have an average health gain of 0.413 QALYs. Patients express on average high overall satisfaction with a rating of 78.8. They are highly satisfied also with hospital cleanliness and involvement in treatment decisions with a rating of 88.1 and 72, respectively. The bed occupancy rate is 87% and the cancelled elective operations rate is 0.81%. The RCIs are standardised to 100 by definition.

[5] The proportion of junior doctors in training and consultants are computed as percentage of the clinical staff including doctors, nurses, and professional healthcare allied (e.g. therapists, healthcare scientists, technicians).

[6] Data on hospital staff are available from 2010-11 onwards. The number of managers, the proportion of junior doctors in training, and the proportion of consultants are therefore omitted in the regressions for the emergency readmission rate estimated by ML to allow comparability between cross-sectional and panel models. The same staff variables are instead included in the regressions for the emergency readmission rate estimated by IV to extend the set of possible instruments.

[7] We exclude lagged demand shifters because they are constructed on catchment populations that are overlapping across rival hospitals.

Table I – Descriptive statistics

Variable	Obs	Trusts	Monop	Mean	Std. dev. Ov	Std. dev. Betw	Std. dev. With	Min	Max
Quality indicator									
Clinical									
Summary Hospital-level Mortality Indicator	476	119	20	99.9	10.0	9.5	3.5	53.9	124.8
Hip fracture mortality rate (%)	424	106	19	7.2	1.9	1.4	1.3	2.4	14.6
Stroke mortality rate (%)	444	111	20	17.4	3.2	2.4	2.2	9.8	32.7
Emergency readmission rate (%)	568	142	20	11.1	1.4	1.3	0.6	5.1	17.2
Patient reported									
Average health change after hip replacement	428	107	19	0.413	0.033	0.022	0.025	0.264	0.538
Overall patient satisfaction	528	132	19	78.8	3.9	3.5	1.8	67.3	90.4
Patient satisfaction on hospital cleanliness	528	132	19	88.1	3.3	3.0	1.3	77.3	96.8
Patient satisfaction on decision involvement	528	132	19	72.0	3.9	3.4	2.0	61.8	85.4
Efficiency indicator									
Bed occupancy rate (%)	536	134	18	87.0	6.5	5.7	3.0	58.3	98.7
Rate of cancelled elective operation (%)	536	134	17	0.81	0.37	0.31	0.19	0.02	2.41
Reference cost index	560	140	18	100.6	10.8	10.2	3.5	81.1	148.2
Elective reference cost index	560	140	18	100.8	15.5	13.6	7.4	62.7	167.7
Non-elective reference cost index	560	140	18	102.4	17.9	16.0	8.1	70.4	213.1
Reference cost index for hip replacement	508	127	18	99.6	24.6	20.4	13.9	37.8	237.1
Control variable									
Demand shifter									
Population density (1,000 indv/km²)				1.808	2.032	2.037	0.041	0.124	7.859
Proportion of elderly individuals (%)				15.7	3.1	3.1	0.6	9.2	25.2
Proportion of individuals employed or looking for a job (%)				70.0	2.9	2.9	0.0	63.9	76.7
Proportion of individuals with a degree (%)				18.4	7.9	7.9	0.0	7.4	35.9
Proportion of households with property house (%)				61.6	8.9	9.0	0.0	40.0	77.6
Proportion of individuals in good or very good health (%)				81.5	2.9	2.9	0.0	75.2	86.8
Supply shifter									
Number of managers (100)				0.66	0.44	0.43	0.11	0.04	3.59
Proportion of junior doctors in training (%)				2.6	1.1	1.1	0.3	0.0	6.7
Proportion of consultants (%)				6.3	1.1	1.0	0.4	2.2	11.7
Number of beds (1,000)				0.631	0.342	0.340	0.042	0.014	2.025
Hospital type									
Foundation trust				0.629	0.484	0.477	0.087	0	1
Teaching hospital				0.184	0.388	0.387	0.038	0	1
Specialist hospital				0.106	0.308	0.387	0.038	0	1

Obs=total number of observations, Trusts=number of non-monopolist hospital trusts, Monop=number of monopolists, Ov=overall, Betw=between, With=within

Descriptive statistics refer to the sample of providers with at least one rival.

Descriptive statistics on control variables are calculated on the overall patient satisfaction's sample.

Descriptive statistics of the regressors are for the overall patient satisfaction's sample. On average, the population density in the catchment area is 1,808 inhabitants per km^2, and 15.7% of individuals is older than 65 years. 70% of individuals are employed or looking for a job, 18.4% have a degree, 61.6% of households own a property house, and 81.5% of individuals are in good or very good health. Hospitals have on average 66 managers. Junior doctors in training and consultants represent respectively 2.6% and 6.3% of clinical staff. Hospitals have on average 631 beds. 83 hospitals (62.9%) are foundation trusts, 24 (18.4%) are teaching, and 14 (10.6%) are specialist.

5. Results

Table II shows the results of the global Moran's I test for quality and efficiency indicators.[8] Spatial correlation is significant (at 5% level) and positive for two clinical (SHMI and emergency readmissions) and two patient-reported (patient satisfaction on overall experience and hospital cleanliness) indicators. Its magnitude varies between moderate (0.150 for overall patient satisfaction in 2012-13) and high (0.528 for SHMI in 2012-13). All four cost indicators have a significant and positive spatial correlation ranging from 0.150 (for RCI for hip replacement in 2011-12) and 0.483 (for RCI in 2013-14).[9]

5.1 ML results

Table III reports the estimated spatial lag coefficient ($\hat{\rho}$) for each quality and efficiency indicator using the ML estimator and after controlling for demand shifters, supply shifters, and type of hospital. In the cross-sectional model, SHMI is the only indicator with a positive and statistically significant estimated spatial lag. 10% lower SHMI (higher quality) in rival hospitals increases on average the hospital's SHMI by 2.9% in 2010-11 and 2% in 2011-12. For other quality and efficiency indicators, we obtain a statistically insignificant or weakly significant (at 10% level) estimated spatial lag with a few exceptions (stroke mortality rate in 2013-14 and non-elective RCI in 2010-11).[10] Overall, there is weak statistical evidence of spatial correlation in cross-sectional models.

Unlike supply shifters and hospital type dummies, demand shifters play a major role in generating cross-sectional spatial correlation. Rival hospitals are indeed close neighbours sharing similar population characteristics. Table A6 (Table A7) in the appendix provides the estimated coefficient for demand shifters, supply shifters, and hospital type in the regressions for the quality (efficiency) indicators. For instance, one more percentage point of elderly individuals increases on average the overall patient satisfaction rating by 0.3 points. An additional manager decreases on average stroke mortality by 1.6 percentage points. Foundation trusts are associated with higher patient satisfaction. While teaching hospitals do not show statistically different quality or efficiency, specialist hospitals have better quality (e.g. lower readmission rates) but lower efficiency (e.g. greater RCIs).

Table III also has estimates of the spatial lag coefficient after controlling for unobserved time-invariant heterogeneity using FE and RE ML. We observe a positive and statistically significant spatial lag for SHMI (0.172) and overall patient satisfaction (0.110).[11] In sum, cross-sectional and panel ML estimates show little statistical evidence in favour of spatial dependence in quality and efficiency. This suggests that hospitals may not respond to rivals in their quality and efficiency decisions.

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[8] The global Moran's I test calculates the overall degree of spatial association between observations (Anselin, 2013). It differs from the local Moran's I test, which provides a measure of spatial clustering for each observation (Anselin, 1995).

[9] Table A3 and Table A4 in the appendix display the local Moran's I test on quality and efficiency indicators in 2010-11 for hospitals which local spatial correlation is statistically significant at 5%. In general, there is some evidence of hospital clustering in the London area. Other hospitals not located in London, however, also exhibit a positive and significant local spatial correlation. The majority of hospitals show an insignificant local spatial correlation.

[10] As a sensitivity check, we risk-adjust the bed occupancy rate and the RCI, which refer to overall hospital activity, by also controlling for proportion of male patients, patient age, and proportion of emergency admissions in equation (8) and (11). As shown in Table A5 in the appendix, results are similar to those reported in Table III.

[11] As showed in Table A8 in the appendix, results for cross-sectional and panel models also mirror the global Moran's I test on the residuals. Residuals are obtained from a linear regression, estimated by OLS, including all controls except the spatial lag of the dependent variable.

Table II – Global Moran's I test for spatial correlation within a radius of 30 km

Indicator	2010-11	2011-12	2012-13	2013-14	All years
Quality					
Clinical					
Summary Hospital-level Mortality Indicator	0.516 (0.000)***	0.460 (0.000)***	0.528 (0.000)***	0.507 (0.000)***	0.487 (0.000)***
Hip fracture mortality rate	0.160 (0.040)**	0.134 (0.081)*	-0.013 (0.968)	0.090 (0.230)	0.081 (0.000)***
Stroke mortality rate	-0.155 (0.067)*	0.126 (0.079)*	-0.073 (0.421)	-0.078 (0.387)	-0.040 (0.060)*
Emergency readmission rate	0.163 (0.009)***	0.235 (0.000)***			0.165 (0.000)***
Patient reported					
Average health change after hip replacement	0.053 (0.438)	0.089 (0.228)	0.037 (0.568)	-0.030 (0.806)	0.041 (0.035)**
Overall patient satisfaction	0.210 (0.002)***	0.202 (0.003)***	0.150 (0.026)**	0.116 (0.080)*	0.158 (0.000)***
Patient satisfaction on hospital cleanliness	0.154 (0.022)**	0.128 (0.056)*	0.160 (0.018)**	0.208 (0.002)***	0.164 (0.000)***
Patient satisfaction on decision involvement	0.093 (0.156)	0.105 (0.113)	0.031 (0.587)	0.116 (0.080)*	0.083 (0.000)***
Efficiency					
Bed occupancy rate	0.069 (0.277)	0.040 (0.502)	-0.098 (0.195)	0.009 (0.813)	0.004 (0.720)
Rate of cancelled elective operations	0.155 (0.019)**	-0.050 (0.546)	0.088 (0.172)	0.046 (0.444)	0.053 (0.002)***
Reference cost index	0.440 (0.000)***	0.425 (0.000)***	0.426 (0.000)***	0.483 (0.000)***	0.439 (0.000)***
Elective reference cost index	0.226 (0.001)***	0.230 (0.000)***	0.293 (0.000)***	0.337 (0.000)***	0.272 (0.000)***
Non-elective reference cost index	0.272 (0.000)***	0.341 (0.000)***	0.273 (0.000)***	0.209 (0.001)***	0.281 (0.000)***
Reference cost index for hip replacement	0.189 (0.006)***	0.150 (0.025)**	0.196 (0.005)***	0.260 (0.000)***	0.201 (0.000)***

Data on the emergency readmission rate are currently available up to 2011-12. The statistic in year 2012-13 and 2013-14 is therefore omitted. The statistic for all years is obtained using data from 2008-09 to 2011-12.

p-values (in parentheses) are calculated assuming a normal distribution of the indicator

***** p-value<0.01, ** p-value<0.05, * p-value<0.1**

Table III – Spatial lag coefficient's ML estimates

Indicator	Cross-Section				Panel	
	2010-11	2011-12	2012-13	2013-14	FE	RE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	0.285 (0.002)***	0.203 (0.044)**	0.108 (0.278)	0.145 (0.194)	0.172 (0.001)***	0.184 (0.000)***
Hip fracture mortality rate	-0.025 (0.831)	0.119 (0.297)	-0.179 (0.116)	-0.156 (0.184)	-0.007 (0.896)	0.002[C] (0.976)
Stroke mortality rate	-0.172 (0.117)	-0.171 (0.136)	-0.174 (0.130)	-0.272 (0.025)**	-0.056 (0.307)	-0.059 (0.299)
Emergency readmission rate	0.070 (0.483)	0.137 (0.140)			0.100 (0.055)*	0.130 (0.010)**
Patient reported						
Average health change after hip replacement	0.048 (0.685)	-0.029 (0.810)	-0.199 (0.097)*	-0.163 (0.124)	-0.044 (0.456)	-0.024[C] (0.682)
Overall patient satisfaction	0.100 (0.178)	0.095 (0.190)	0.048 (0.534)	0.105 (0.185)	0.110 (0.034)**	0.122 (0.005)***
Patient satisfaction on hospital cleanliness	-0.012 (0.898)	0.000 (0.998)	-0.061 (0.497)	0.086 (0.313)	-0.063 (0.261)	-0.023 (0.647)
Patient satisfaction on decision involvement	0.024 (0.778)	0.048 (0.561)	-0.073 (0.398)	0.055 (0.543)	-0.023 (0.668)	0.016 (0.740)
Efficiency						
Bed occupancy rate	-0.008 (0.932)	-0.015 (0.887)	-0.173 (0.073)*	-0.079 (0.442)	-0.031 (0.559)	-0.023[C] (0.655)
Rate of cancelled elective operations	0.068 (0.476)	-0.157 (0.151)	0.032 (0.749)	-0.008 (0.934)	0.053 (0.289)	0.044[C] (0.380)
Reference cost index	-0.087 (0.378)	-0.079 (0.412)	-0.067 (0.513)	0.003 (0.980)	0.007 (0.900)	0.018 (0.732)
Elective reference cost index	-0.003 (0.973)	-0.094 (0.323)	-0.051 (0.612)	-0.030 (0.776)	-0.039 (0.447)	-0.039[C] (0.437)
Non-elective reference cost index	-0.211 (0.037)**	-0.108 (0.248)	-0.168 (0.092)*	-0.121 (0.287)	-0.072 (0.185)	-0.060 (0.251)
Reference cost index for hip replacement	-0.054 (0.626)	-0.117 (0.332)	0.067 (0.532)	0.085 (0.448)	-0.041 (0.474)	-0.021 (0.707)

Each cross-sectional regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. Cross-sectional estimates in year 2012-13 and 2013-14 are therefore omitted. Panel estimates are obtained using data from 2008-09 to 2011-12. In addition, data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

5.2 Sensitivity analysis

As a robustness check, we estimate the spatial lag WY through the SAC model, which allows for spatial correlation in the error term. Also in this case, cross-sectional and panel estimates show weak statistical significance for the spatial lag of quality and efficiency indicators (Table IV).[12] We also test whether a hospital's quality (efficiency) responds to rivals' efficiency (quality).[13] Results in Table V are similar to those in Table III.[14] Finally, Table A12 and Table A13 in the appendix suggest that our key results are robust to competition areas with a larger radius (60 km or 90 km).[15]

5.3 IV results

Table VI shows IV estimates of the spatial lag coefficient $\hat{\rho}$ for some quality and efficiency indicators.[16] In the first IV approach, WY_{t-3} is valid for six quality indicators (except for stroke mortality and average health change after hip replacement) and for all efficiency indicators. The estimates consistently show no spatial correlation in quality and efficiency in 2013-14. In the second IV approach, a lagged supply shifter is a valid instrument for five quality indicators (except for the condition-specific outcomes) and five efficiency indicators (except for the RCI for hip replacement).[17] For both quality and efficiency indicators, the spatial lag estimates do not exhibit any statistical significance at 5% level (except for SHMI in 2010-11). On the whole, similarly to ML estimates, IV estimates suggest the absence of spatial correlation in quality and efficiency.

The results in our study are compatible with those reported in Gravelle et al. (2014b), who analyse sixteen quality indicators for English hospitals in 2009-10. The two studies have five indicators in common: three mortality indicators such as overall mortality, hip fracture and stroke mortality, and two patient satisfaction indicators such as satisfaction on hospital cleanliness and decision involvement.[18] Table A17 provides a direct comparison of the results. If we compare results from Gravelle et al. (2014b) in 2009-10 with ours in 2010-11 and 2011-12 (the two closest years), the spatial lag is significant for overall mortality and it is insignificant for hip fracture mortality for both studies. Stroke mortality is weakly significant in Gravelle et al. (2014b) and insignificant in our study. The results for the patient satisfaction indicators differ. They are significant or weakly significant in Gravelle et al. (2014b) but they are insignificant in ours. For patient satisfaction on hospital cleanliness, this is due to the different years used in the analyses. For patient satisfaction on decision involvement, differences are due to the different analysed years and additional demand shifters in our analysis.[19]

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[12] In Table A9 in the appendix, we show the results for the Likelihood Ratio test comparing spatial lag model and SAC model. The test suggests that SAC is the correct model only for the rate of cancelled elective operations.

[13] We use rivals' bed occupancy rate and reference cost index as measures of rivals' efficiency, and rivals' SHMI and overall patient satisfaction as measures of rivals' quality.

[14] In line with our theoretical predictions, we do not generally observe an effect of rivals' efficiency on a hospital's quality (Table A10). Unlike our theoretical model, however, we find weak evidence of rivals' quality affecting a hospital's efficiency (Table A11). For instance, higher rivals' quality, as measured by the SHMI, is significantly associated at 5% level with better efficiency, as measured by the elective RCI, in 2010-11, 2011-12, and 2012-13. Such an association is only weakly significant (at 10% level) in 2013-14 and disappears in the panel model.

[15] Table A12 and Table A13 in the appendix also show that the number of monopolist hospitals drops to one or zero when the radius is expanded to 60 km or 90 km, respectively.

[16] Table A14 and Table A15 in the appendix include first-stage estimate on the instrument and F statistic. As a rule of thumb, we assess the instrument as relevant if the first-stage F statistic is greater than 10 (Staiger and Stock, 1997).

[17] In Table A16, we empirically test the exclusion restriction on the chosen instrument. We reject this assumption only once (patient satisfaction on decision involvement in 2010-11).

[18] Gravelle et al. (2014b) explore spatial correlation for other indicators not included in this study. Amongst these, they find a positive and significant spatial correlation for hip replacement readmissions and patient satisfaction on trust in the doctors. No (or weak) spatial correlation is instead observed for mortality from high and low risk conditions, deaths after surgery, hip replacement and stroke readmissions, hip and knee revisions, operations within two days from hip fracture, and redo rates for prostate resection.

[19] The additional demand shifters are: proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, and proportion of individuals in good or very good health.

Table IV – Spatial lag coefficient's ML estimates after controlling for spatially correlated disturbances

Indicator	Spatial lag	Cross-Section				Panel
		2010-11	2011-12	2012-13	2013-14	FE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	*P*	0.331**	0.108	0.240	0.085	0.345***
	λ	-0.080	0.154	-0.198	0.105	-0.204
Hip fracture mortality rate	*P*	0.133	0.045	0.193	0.239	-0.298
	λ	-0.215	0.095	-0.450**	-0.429**	0.275*
Stroke mortality rate	*P*	0.099	-0.063	-0.293	-0.243	-0.009
	λ	-0.341	-0.132	0.145	-0.047	-0.051
Emergency readmission rate	*P*	0.160	0.360***			0.051
	λ	-0.152	-0.348**			0.052
Patient reported						
Average health change after hip replacement	*P*	-0.104	-0.001	-0.135	-0.017	0.012
	λ	0.193	-0.044	-0.093	-0.208	-0.063
Overall patient satisfaction	*P*	0.224***	0.117	0.097	0.033	0.199
	λ	-0.342**	-0.082	-0.107	0.142	-0.100
Patient satisfaction on hospital cleanliness	*P*	-0.016	0.051	0.005	0.140	-0.027
	λ	0.007	-0.093	-0.124	-0.095	-0.039
Patient satisfaction on decision involvement	*P*	-0.089	0.025	0.056	0.102	-0.093
	λ	0.189	0.043	-0.202	-0.080	0.071
Efficiency						
Bed occupancy rate	*P*	0.348**	0.006	-0.410***	-0.076	0.059
	λ	-0.417**	-0.030	0.295*	-0.004	-0.099
Rate of cancelled elective operations	*P*	0.549***	-0.013	0.418***	0.389***	-0.474***
	λ	-0.570***	-0.170	-0.510***	-0.507***	0.491***
Reference cost index	*P*	0.043	0.042	0.012	0.101	0.017
	λ	-0.219	-0.225	-0.124	-0.166	-0.012
Elective reference cost index	*P*	-0.215	0.086	0.083	0.107	-0.374***
	λ	0.261	-0.221	-0.192	-0.223	0.336***
Non-elective reference cost index	*P*	0.002	0.093	0.055	-0.013	-0.171
	λ	-0.304*	-0.341**	-0.315*	-0.175	0.114
Reference cost index for hip replacement	*P*	0.122	-0.032	0.048	0.150	-0.066
	λ	-0.267	-0.117	0.038	-0.085	-0.001

Each cross-sectional regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. Cross-sectional estimates in year 2012-13 and 2013-14 are therefore omitted. Panel estimates are obtained using data from 2008-09 to 2011-12. In addition, data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

The p-value is omitted. *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table V – Spatial lag coefficient's ML estimates after controlling for rivals' quality or efficiency

Indicator	Cross-Section				Panel	
	2010-11	2011-12	2012-13	2013-14	FE	RE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	0.212 (0.043)**	0.159 (0.130)	0.098 (0.328)	0.156 (0.164)	0.170 (0.001)***	0.181 (0.000)***
Hip fracture mortality rate	0.016 (0.891)	0.094 (0.403)	-0.199 (0.085)*	-0.205 (0.083)*	-0.040 (0.468)	-0.021[C] (0.710)
Stroke mortality rate	-0.156 (0.156)	-0.176 (0.132)	-0.189 (0.097)*	-0.305 (0.013)**	-0.060 (0.279)	-0.057[C] (0.316)
Emergency readmission rate	0.091 (0.327)	0.092 (0.351)			0.065 (0.233)	0.114 (0.028)**
Patient reported						
Average health change after hip replacement	-0.006 (0.958)	-0.064 (0.606)	-0.157 (0.207)	-0.195 (0.082)*	-0.039 (0.505)	-0.035[C] (0.557)
Overall patient satisfaction	0.047 (0.568)	0.061 (0.460)	0.003 (0.971)	0.084 (0.349)	0.084 (0.113)	0.092 (0.052)*
Patient satisfaction on hospital cleanliness	-0.016 (0.873)	-0.054 (0.565)	-0.082 (0.371)	0.044 (0.624)	-0.069 (0.218)	-0.045 (0.382)
Patient satisfaction on decision involvement	0.035 (0.719)	0.075 (0.405)	-0.130 (0.163)	0.029 (0.761)	-0.032 (0.552)	-0.001 (0.986)
Efficiency						
Bed occupancy rate	-0.054 (0.619)	-0.114 (0.333)	-0.097 (0.401)	0.049 (0.641)	-0.090 (0.136)	-0.053[C] (0.367)
Rate of cancelled elective operations	0.084 (0.424)	-0.024 (0.839)	0.125 (0.246)	0.040 (0.713)	0.018 (0.736)	0.050 (0.353)
Reference cost index	0.016 (0.886)	0.034 (0.757)	0.030 (0.787)	-0.049 (0.682)	0.046 (0.430)	0.059 (0.297)
Elective reference cost index	0.016 (0.886)	0.034 (0.757)	0.030 (0.787)	-0.049 (0.682)	0.046 (0.430)	0.059 (0.297)
Non-elective reference cost index	-0.064 (0.572)	-0.081 (0.468)	-0.145 (0.189)	-0.018 (0.884)	-0.076 (0.179)	0.025 (0.647)
Reference cost index for hip replacement	-0.122 (0.287)	-0.187 (0.092)*	-0.012 (0.919)	0.068 (0.555)	-0.107 (0.058)*	-0.070 (0.212)

Each cross-sectional regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The efficiency indicators added to the regressions for the quality indicators are bed occupancy rate and RCI. The quality indicators added to the regressions for the efficiency indicators are SHMI and overall patient satisfaction. The panel model also includes year dummies.

In the regressions including SHMI, hip fracture and stroke mortality as dependent or independent variable, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. Cross-sectional estimates in year 2012-13 and 2013-14 are therefore omitted. Panel estimates are obtained using data from 2008-09 to 2011-12. In addition, data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table VI – Spatial lag coefficient's IV estimates

Indicator	IV 1	IV 2			
	2013-14	2010-11	2011-12	2012-13	2013-14
Quality					
Clinical					
Summary Hospital-level Mortality Indicator	0.519 (0.090)*	0.889 (0.012)**	0.638 (0.061)*	0.272 (0.587)	0.534 (0.357)
Hip fracture mortality rate	-0.035 (0.939)				
Emergency readmission rate	0.307 (0.087)*	0.350 (0.156)	0.524 (0.093)*		
Patient reported					
Overall patient satisfaction	0.089 (0.467)	0.063 (0.600)	0.061 (0.606)	0.004 (0.976)	-0.079 (0.585)
Patient satisfaction on hospital cleanliness	0.155 (0.218)	-0.174 (0.358)	-0.092 (0.630)	-0.072 (0.696)	0.068 (0.711)
Patient satisfaction on decision involvement	0.266 (0.081)*	-0.354 (0.079)*	-0.170 (0.362)	-0.131 (0.479)	-0.075 (0.697)
Efficiency					
Bed occupancy rate	0.0003 (0.999)	-0.169 (0.617)	0.016 (0.973)	-0.418 (0.312)	0.162 (0.731)
Rate of cancelled elective operations	-0.074 (0.792)	-0.495 (0.788)	0.349 (0.734)	0.311 (0.469)	-0.463 (0.234)
Reference cost index	-0.110 (0.518)	-0.408 (0.311)	-0.195 (0.493)	-0.230 (0.641)	-0.454 (0.337)
Elective reference cost index	0.027 (0.920)	-0.982 (0.055)*	-0.684 (0.074)*	-0.686 (0.150)	-1.604 (0.214)
Non-elective reference cost index	-0.339 (0.272)	-0.163 (0.635)	0.271 (0.294)	0.298 (0.528)	-0.305 (0.623)
Reference cost index for hip replacement	0.625 -(0.109)				

IV 1 = IV strategy using the three-year lagged spatial lag of the dependent variable as instrument (*WY_{t-3}*).

IV 2 = IV strategy using a spatially lagged supply shifter as instrument (*WZ*). The instruments for the IV 2 strategy are: (spatially) lagged proportion of consultants for the lagged SHMI mortality rate; lagged proportion of junior doctors in training for lagged emergency readmission rate, lagged overall patient satisfaction, lagged patient satisfaction on hospital cleanliness, lagged patient satisfaction on decision involvement, lagged reference cost index, lagged elective and non-elective reference cost index; lagged number of managers for lagged bed occupancy rate and lagged rate of cancelled elective operations.

Each regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. For IV 1, the estimate refers to the latest available year (2011-12) and not to 2013-14. For IV 2, estimates in year 2012-13 and 2013-14 are omitted.

For stroke mortality and average health change after hip replacement, IV 1 and IV 2's estimates are omitted because of the absence of valid instruments. Similarly, IV 2's estimates are omitted for hip fracture mortality and RCI for hip replacement.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

6. Conclusions

This study investigates whether a hospital's quality or efficiency responds to an increase in quality or efficiency of its rivals. First, we test for spatial correlation by global Moran's I test and find evidence of a positive spatial correlation amongst some quality and efficiency indicators. Second, we estimate spatial cross-sectional models by ML and no longer observe a statistically significant spatial correlation in most indicators. Similarly, we observe little evidence of spatial correlation after controlling for unobserved time-invariant heterogeneity through a spatial panel model estimated by ML. Finally, our two spatial cross-sectional IV approaches further suggest the absence of spatial correlation for both quality and efficiency indicators. Hospital quality (efficiency), therefore, does not appear to respond to the quality (efficiency) of neighbouring hospitals.

In conclusion, our empirical analysis suggests the absence of hospital spillovers in quality and efficiency. These findings have important policy implications. They suggest that interventions incentivising quality or efficiency at local level may not affect other hospitals. The results have implications for antitrust policies. Our study suggests that hospital mergers that might increase efficiency of merging hospitals (as a result of better scale economies) at the cost of reducing their quality (as a result of reduced competition) will not induce non-merging hospitals also to increase efficiency or reduce quality.

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Appendix

Table A1 – definition for the quality indicators

Quality indicators
The Summary Hospital-level Mortality Indicator (SHMI) is a ratio of the observed number of deaths to the expected number of deaths for a trust (provider). The observed number of deaths is the total number of finished provider spells for the trust which resulted in a death either in-hospital or within 30 days (inclusive) of discharge from the trust. The expected number of deaths is calculated from a risk-adjusted model with a patient case-mix of age, gender, admission method, year index, Charlson Comorbidity Index and diagnosis grouping. A three year dataset is used to create the risk-adjusted models.
The hip fracture mortality rate captures deaths within 30 days (from 0 to 29 days inclusive) of an emergency admission to hospital with a primary diagnosis of fractured proximal femur (ICD-10 codes S720, S721, S722). It is indirectly standardised by age and sex.
The stroke mortality rate captures deaths within 30 days (from 0 to 29 days inclusive) of an emergency admission to hospital with a primary diagnosis of stroke (all ICD-10 codes from I61 to I64). It is indirectly standardised by age and sex.
The emergency readmission rate captures the percentage of emergency admission to any hospital in England occurring within 28 days of the last discharge from hospital after admission. The rate is calculated considering all patients aged between 16 and 74. It is indirectly standardised by age, sex, method of admission of discharge spell, diagnosis within medical specialties, and procedure within surgical specialties.
***Source*: Health and Social Care Information Centre, NHS Digital Indicator Portal**
***Link*: https://indicators.hscic.gov.uk/webview/**
The average health change after hip replacement is extracted from PROMs data. PROMs comprise a pair of questionnaires completed by the patient, one before and one after surgery (at least six months after for hip replacements). All patients, irrespective of their condition, are asked to complete a common set of questions about their health status. This includes sections about the patient's circumstances, pre-existing conditions and the EQ-5D health questionnaire consisting of a five-dimensional descriptive system and a visual analogue scale (EQ-VAS). Post-operative questionnaires also contain additional questions about the surgery, such as how the patient perceives the results of the operation and whether there were any post-operative complications, such as bleeding or wound problems. Patients undergoing hip replacement surgery are also asked to complete a condition-specific section. The collected data are risk-adjusted for patient characteristics (e.g. gender, age, ethnics), initial health status, self-assessed health status, economic deprivation, comorbidity, procedure, and post-operative length of stay.
***Source*: Health and Social Care Information Centre**
***Link*: http://content.digital.nhs.uk/proms**
Patient satisfaction indicators are derived from the NHS Inpatient Surveys for the Care Quality Commission which is administered to a random sample of patients in all acute trusts. The variables relate to three questions to patients: 1) From 0 to 100, "Overall, how would you rate the care you received?" (Overall patient satisfaction); 2) From 0 to 100, "In your opinion, how clean was the hospital room or ward that you were in?" (Satisfaction on hospital cleanliness); 3) From 0 to 100, "Were you involved as much as you wanted to be in decisions about your care and treatment?" (Satisfaction on decision involvement). The data has been standardised to adjust for these differences in patient-mix using the respondent's age, gender, ethnic group and method of admission (emergency or elective).
***Source*: NHS patient surveys**
***Links*: http://www.nhssurveys.org/surveys , https://www.kingsfund.org.uk/publications/patients-experience-using-hospital-services**

Table A2 – Definition for the efficiency indicators

Efficiency indicators
The bed occupancy rate is the ratio of the overnight occupied beds to the overnight available beds. For wards open overnight, an occupied bed day is defined as one which is occupied at midnight on the day in question. The number of occupied beds excludes any bed days of occupation by well babies. The number of available beds only includes beds in units managed by the provider, not beds commissioned from other providers. It excludes any beds designated solely for the use of well babies. Such data are available quarterly.
The rate of cancelled elective operations is the ratio of the number of last minute cancellations by the hospital for non-clinical reasons to the number of elective patients. Last minute means on the day the patient was due to arrive, after the patient has arrived in hospital, or on the day of the operation or surgery. Elective cancelled operations are provided in each quarter. The number of elective patients is calculated as the sum of planned and waiting list admissions, where the admission is a finished admission episode, i.e. the first period of inpatient care under one consultant within one healthcare provider. The number of elective patients is published annually.
Source: NHS statistics
Link: https://www.england.nhs.uk/statistics/statistical-work-areas/
The reference cost index shows the actual cost of an organisation's case-mix compared with the same case-mix delivered at national average cost. Each organisation's reference cost index is calculated by dividing its total costs (unit costs × activity) by the expected costs (national average mean unit cost × activity). The reference cost index is computed separately also for elective and non-elective activity. Elective activity refers to patients whose admission to hospital is planned, including day case patients. Non-elective activity refers to patients whose admission is not planned, including emergency admissions and admissions for maternity, births, and non-emergency patient transfers, and requires staying in hospital for more than one day. The reference cost index for hip replacement is calculated selecting the HRG codes: HB11A, HB11B, HB11C, HB12A, HB12B, and HB12C.
Source: Reference costs data
Link: https://www.gov.uk/government/collections/nhs-reference-costs

Table A3 – Local Moran's I test for spatial correlation within a radius of 30 km for seven quality indicators

SHMI			Hip fracture mortality			Stroke mortality			Emergency readmissions			Health change after hip repl.			Overall patient satisfaction			Satisfaction on hospital cleanliness		
Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc
-0.576	Yes	HL	0.632	No	HH	-2.386	No	HL	-1.280	No	LH	-1.570	No	HL	-4.573	Yes	HL	-2.402	No	HL
0.626	Yes	LL	1.041	No	LL	-1.301	Yes	HL	-1.132	No	LH	-1.384	Yes	LH	-0.656	Yes	LH	-0.763	No	HL
0.665	Yes	LL	1.134	No	HH	-1.006	No	LH	-0.634	Yes	HL	-0.868	No	HL	-0.648	No	LH	-0.754	No	LH
0.879	Yes	LL	1.452	No	HH	0.587	No	HH	-0.457	Yes	LH	0.982	No	LL	-0.428	Yes	HL	0.414	Yes	LL
0.903	No	HH	1.506	No	LL	0.634	Yes	LL	0.460	No	HH	2.481	No	LL	0.410	No	LL	0.422	Yes	LL
1.057	Yes	LL	1.864	No	HH	0.670	Yes	LL	1.055	No	HH				0.465	No	LL	0.491	Yes	LL
1.084	No	LL	2.299	No	LL	0.775	Yes	LL	1.204	No	HH				0.619	Yes	LL	0.508	Yes	LL
1.108	No	HH	2.485	No	LL	1.020	Yes	LL	1.424	No	HH				0.818	No	HH	0.535	No	LL
1.132	Yes	LL				1.159	No	HH	1.501	Yes	LL				0.940	No	LL	0.617	Yes	LL
1.142	No	HH				1.210	No	HH	1.650	No	HH				1.005	No	HH	0.718	Yes	LL
1.289	Yes	LL				1.319	Yes	LL	1.706	No	HH				1.009	No	LL	0.753	Yes	LL
1.332	Yes	LL				1.514	No	HH	1.737	Yes	LL				2.002	No	HH	0.864	No	LL
1.452	Yes	LL				1.563	Yes	LL	1.851	No	HH				2.216	No	HH	0.907	No	LL
1.596	Yes	LL				1.620	Yes	LL	2.157	No	HH				2.592	No	HH	0.924	Yes	LL
1.692	Yes	LL				2.045	Yes	LL	3.764	No	LL				2.922	Yes	HH	0.978	Yes	LL
1.840	Yes	LL				2.163	Yes	LL	3.764	No	LL				2.923	Yes	HH	1.224	No	LL
2.008	No	HH				2.376	Yes	LL										1.716	Yes	LL
2.008	No	HH																1.729	No	HH
2.044	No	LL																1.805	Yes	LL
2.060	Yes	LL																1.810	No	HH
2.645	Yes	LL																2.077	No	HH
3.135	Yes	LL																2.151	No	HH
3.881	Yes	LL																		
4.007	Yes	LL																		
4.291	Yes	LL																		
4.821	Yes	LL																		
No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts		
119			106			111			142			107			132			132		
Lon=London, Sc=Spatial cluster, LL=low-low, HH=high-high, LH=low-high, HL=high-low																				
Each statistic represents the local spatial correlation of a single hospital. We only show statistics that are significant at 5% level.																				

Table A4 – Local Moran’s I test for spatial correlation within a radius of 30 km for a quality indicator and six efficiency indicators

Satisfaction on decision involvement			Bed occupancy rate			Cancelled elective procedures			RCI			Elective RCI			Non-elective RCI			RCI for hip replacement		
Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc	Statistic	Lon	Sc
-3.661	No	HL	-4.220	No	LH	-2.430	No	LH	-2.300	No	HL	-2.256	No	HL	-2.648	No	HL	-1.942	No	LH
-1.894	No	LH	-4.220	No	HL	-1.587	No	HL	-2.285	No	LH	-1.960	No	LH	-2.648	No	LH	-1.782	Yes	LH
-0.810	No	LH	-1.423	No	LH	-0.540	Yes	HL	0.559	Yes	HH	-1.856	No	HL	-2.308	Yes	LH	-1.754	No	LH
0.505	Yes	LL	-0.959	Yes	LH	0.465	Yes	LL	0.583	Yes	HH	-1.781	No	LH	-1.723	No	LH	-1.346	No	LH
0.509	Yes	LL	-0.907	No	LH	0.854	No	LL	0.640	Yes	HH	-0.913	No	LH	-1.573	No	HL	-0.801	Yes	LH
0.526	Yes	LL	0.435	Yes	HH	0.955	No	LL	0.684	Yes	HH	-0.805	Yes	LH	-0.783	No	HL	-0.572	Yes	LH
0.564	Yes	LL	0.487	Yes	HH	1.056	No	LL	0.751	Yes	HH	-0.727	Yes	LH	-0.672	No	LH	0.501	Yes	HH
0.655	Yes	LL	0.541	Yes	HH	1.294	No	HH	0.822	Yes	HH	-0.543	Yes	LH	0.864	Yes	HH	0.821	No	HH
0.672	Yes	LL	0.620	Yes	HH	3.192	No	HH	1.011	Yes	HH	0.608	Yes	HH	1.174	Yes	HH	0.871	Yes	HH
0.733	Yes	LL	0.888	No	LL				1.194	Yes	HH	0.659	No	HH	1.176	No	LL	0.908	No	HH
1.256	No	HH	1.057	No	LL				1.242	Yes	HH	0.694	Yes	HH	1.702	Yes	HH	1.079	Yes	HH
1.688	Yes	HH	1.288	No	HH				1.327	Yes	HH	0.974	Yes	HH	2.343	Yes	HH	1.161	Yes	HH
1.733	No	HH	2.449	No	HH				1.515	Yes	HH	1.002	Yes	HH	2.514	Yes	HH	1.245	Yes	HH
1.972	Yes	HH	2.451	No	LL				2.583	Yes	HH	1.178	Yes	HH	2.523	Yes	HH	1.366	No	LL
2.119	No	HH							2.855	Yes	HH	1.376	Yes	HH	2.597	Yes	HH	1.426	No	LL
2.119	No	HH							3.124	Yes	HH	1.421	Yes	HH	2.903	Yes	HH	1.428	Yes	HH
									3.575	Yes	HH	1.661	Yes	HH	3.030	Yes	HH	1.705	Yes	HH
									3.778	Yes	HH	1.846	Yes	HH	4.194	Yes	HH	1.807	Yes	HH
									4.190	Yes	HH	1.860	Yes	HH	4.910	Yes	HH	1.955	Yes	HH
									4.247	Yes	HH	1.913	Yes	HH	6.292	Yes	HH	1.973	Yes	HH
									4.554	Yes	HH	1.956	No	LL	6.549	Yes	HH	2.837	Yes	HH
									6.084	Yes	HH	1.956	No	LL				2.906	Yes	HH
									7.021	Yes	HH	2.032	Yes	HH				2.978	Yes	HH
												2.768	Yes	HH						
												4.490	Yes	HH						
												5.464	Yes	HH						
No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts			No. of trusts		
132			134			134			140			140			140			127		

Lon=London, Sc=Spatial cluster, LL=low-low, HH=high-high, LH=low-high, HL=high-low

Each statistic represents the local spatial correlation of a single hospital. We only show statistics that are significant at 5% level.

Table A5 – ML estimates for bed occupancy rate and RCI including controls for risk-adjustment

	Regressors	Bed occupancy rate					Reference cost index				
		2010-11	2011-12	2012-13	2013-14	FE	2010-11	2011-12	2012-13	2013-14	FE
	Spatial lag of the dependent variable	0.002	0.018	-0.115	-0.011	-0.025	-0.053	-0.044	-0.042	0.023	0.003
Demand shifter	Population density	0.648	-0.508	-0.339	1.176*	-6.994	1.924**	1.623*	1.604*	1.797**	-5.848
	Prop. of elderly individuals	-0.396	-0.898**	-0.624*	-0.246	0.702	-0.062	-0.739	-1.210***	-0.783*	1.510*
	Prop. of ind. empl. or looking for a job	-0.483	-0.365	-0.415	-0.147		0.582	0.408	0.519	0.973*	
	Prop. of individuals with a degree	-0.138	0.113	0.079	-0.373**		0.303	0.151	0.336	0.481**	
	Prop. of households with property house	0.111	0.189	0.213	0.148		0.100	0.196	0.357	0.482**	
	Prop. of ind. in good/very good health	0.887	0.272	0.277	0.925		-0.168	0.178	-0.876	-1.135	
Cost shifter	Number of managers	-0.717	-0.701	-1.666	0.191	1.953*	1.996	1.946	3.339*	1.526	-1.506
	Prop. of junior doctors in training	-0.430	-0.725	-0.504	-0.476	1.934***	0.526	0.224	-0.354	-0.299	-1.727**
	Prop. of consultants	-1.871***	-0.719	-0.226	-0.657	-1.019**	-1.962***	-0.848	-0.202	0.324	-0.051
	Number of beds	-3.092	-3.359	-1.203	-1.021	-15.677***	0.812	0.825	-3.963	-0.628	4.414
Type	Foundation trust	-2.314**	-2.687**	-2.381**	-2.351**	-1.355	-1.970	-2.748**	-2.088	-2.229*	-4.866***
	Teaching hospital	0.503	-1.126	-4.018**	-0.460	0.994	-0.203	-1.105	-2.153	-1.991	-2.373
	Specialist hospital	-1.435	-3.114	-11.796***	-4.559		6.230	5.038	-2.938	-0.701	
Risk-adjustment	Prop. of male patients	0.810***	0.703***	0.841***	0.630***	0.508**	1.067***	0.689***	0.334*	0.287	0.554**
	Prop. of patients between 15 and 59	0.282***	0.317***	0.225***	0.109	0.178	0.341***	0.181	0.134	0.140	-0.085
	Prop. of patients between 60 and 74	-0.539***	-0.439***	-0.361***	-0.352***	-0.248	-0.377**	-0.181	0.131	0.131	-0.101
	Prop. of patients beyond 74	0.531***	0.522***	0.234	0.358**	0.610**	-0.096	-0.374*	-0.148	-0.320	-0.032
	Prop. of emergency patients	0.000	0.034	-0.044	-0.001	-0.158**	-0.340***	-0.229**	-0.327***	-0.207*	-0.042
	Constant	17.109	52.175	65.769**	-2.138		34.205	41.282	123.793***	86.284**	
Variance		22.91***	26.31***	23.49***	22.14***	7.99***	38.24***	39.52***	39.13***	38.25***	11.42***
Observations		134	134	134	134	536	140	140	140	140	560
Year dummies are included in the panel model but not reported											
The RE estimator is not reported because always statistically inconsistent											
*** p-value<0.01, ** p-value<0.05, * p-value<0.1											

Table A6 – ML estimates for the quality indicators in 2013-14

	Regressors	SHMI	Hip fract. mortality	Stroke mortality	Emerg. readm.	Health change hip repl.	Overall satisf.	Satisf. on cleanlin.	Satisf. on involvem.
	Spatial lag of the dependent variable	0.145	-0.156	-0.272**	0.137	-0.163	0.105	0.086	0.055
Demand shifter	Population density	-0.903	0.032	0.240	-0.052	0.009**	0.156	0.246	-0.058
	Proportion of elderly individuals	-0.037	-0.268**	0.089	-0.216**	0.004***	0.330**	0.322**	0.624***
	Proportion of ind. employed or looking for a job	0.237	0.148	-0.109	-0.037	-0.001	0.044	0.058	0.080
	Proportion of individuals with a degree	-0.397	0.052	0.060	0.031	-0.002*	-0.069	-0.157*	-0.073
	Proportion of households with property house	0.019	0.103*	0.041	0.002	0.0000	-0.086	-0.081	-0.196*
	Proportion of ind. in good/very good health	-0.603	-0.541***	-0.164	-0.200	0.008**	0.147	0.043	0.279
Cost shifter	Number of managers	-1.797	-0.315	-1.606**		-0.004	0.435	-0.888	0.293
	Proportion of junior doctors in training	0.917	-0.016	0.637		-0.016***	-0.664**	-0.587**	-0.827**
	Proportion of consultants	-0.605	-0.160	0.404		0.002	0.090	0.117	0.049
	Number of beds	2.667	-0.165	-0.767	0.362	0.010	0.578	1.357	1.272
Type	Foundation trust	0.432	-0.224	-0.480	-0.049	-0.002	1.44***	0.523	1.434**
	Teaching hospital	-2.005	0.698	0.149	-0.160	-0.010	0.838	1.172	0.693
	Specialist hospital				-1.257***	-0.024	5.434***	4.620***	5.795***
	Constant	126.827***	39.683***	34.329*	31.199***	-0.067	56.281***	75.031***	43.391**
Variance		42.184	2.058***	8.212***	1.422***	0.001***	4.094***	5.156***	8.019***
Observations		119	106	111	142	107	132	132	132

Only cross-sectional results for 2013-14 are reported. Results for the emergency readmission rate refer to the most recent available financial year (2011-12).

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Estimates for the emergency readmission rate refer to 2011-12. Data on this variable are currently available up to 2011-12. Data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

***** p-value<0.01, ** p-value<0.05, * p-value<0.1**

Table A7 – ML estimates for the efficiency indicators in 2013-14

	Regressors	Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	RCI for hip repl.
	Spatial lag of the dependent variable	-0.079	-0.008	0.003	-0.030	-0.121	0.096
Demand shifter	Population density	1.529**	0.043	2.06**	2.813**	1.754	0.590
	Proportion of elderly individuals	0.018	-0.010	-0.942**	-0.831	-0.821	-0.140
	Proportion of ind. employed or looking for a job	-0.215	0.016	1.341**	0.824	2.832**	2.623*
	Proportion of individuals with a degree	-0.421**	-0.027**	0.519**	-0.234	1.045**	0.635
	Proportion of households with property house	0.143	0.007	0.526**	0.036	0.482	-0.723
	Proportion of ind. in good/very good health	1.194*	0.028	-1.474*	0.141	-3.247*	-2.512
Cost shifter	Number of managers	0.364	0.048	2.602	0.147	3.677	-3.900
	Proportion of junior doctors in training	-0.051	-0.037	-0.398	1.164	0.205	1.974
	Proportion of consultants	-0.237	0.028	0.489	0.406	0.839	-1.076
	Number of beds	1.123	0.010	-0.018	-4.200	3.977	11.189
Type	Foundation trust	-2.458**	-0.145**	-1.342	-2.186	-1.717	4.757
	Teaching hospital	-1.148	0.170	0.614	2.456	0.087	-5.376
	Specialist hospital	-5.618*	-0.048	9.426***	11.789**	21.428***	25.155
	Constant	11.159	-2.494	91.661**	41.426	129.643	135.915
Variance		28.800***	0.118***	41.994***	110.523***	193.989***	298.786***
Observations		134	134	140	140	140	127
Only cross-sectional results for 2013-14 are reported							
***** p-value<0.01, ** p-value<0.05, * p-value<0.1**							

Table A8 – Global Moran's I test for spatial correlation within a radius of 30 km on the residuals

Indicator	2010-11	2011-12	2012-13	2013-14	All years
Quality					
Clinical					
Summary Hospital-level Mortality Indicator	0.148 (0.036)**	0.117 (0.092)*	0.038 (0.535)	0.081 (0.222)	0.086 (0.000)***
Hip fracture mortality rate	-0.049 (0.633)	0.073 (0.314)	-0.152 (0.084)*	-0.124 (0.166)	-0.019 (0.430)
Stroke mortality rate	-0.139 (0.108)	-0.114 (0.183)	-0.075 (0.405)	-0.109 (0.215)	-0.048 (0.023)**
Emergency readmission rate	0.025 (0.620)	0.047 (0.393)			0.040 (0.009)***
Patient reported					
Average health change after hip replacement	0.046 (0.487)	-0.022 (0.879)	-0.105 (0.242)	-0.122 (0.169)	-0.003 (0.976)
Overall patient satisfaction	-0.029 (0.764)	0.007 (0.835)	-0.001 (0.928)	0.099 (0.132)	0.030 (0.075)*
Patient satisfaction on hospital cleanliness	-0.004 (0.958)	-0.025 (0.806)	-0.068 (0.393)	0.028 (0.611)	0.002 (0.824)
Patient satisfaction on decision involvement	0.036 (0.543)	0.041 (0.491)	-0.079 (0.312)	0.017 (0.729)	0.032 (0.058)*
Efficiency					
Bed occupancy rate	-0.020 (0.857)	-0.012 (0.952)	-0.083 (0.283)	-0.042 (0.621)	-0.024 (0.205)
Rate of cancelled elective operations	0.047 (0.435)	-0.088 (0.252)	-0.008 (0.991)	-0.015 (0.909)	-0.020 (0.290)
Reference cost index	-0.090 (0.219)	-0.097 (0.184)	-0.065 (0.390)	-0.038 (0.648)	-0.066 (0.000)***
Elective reference cost index	0.028 (0.603)	-0.075 (0.317)	-0.059 (0.439)	-0.057 (0.458)	-0.020 (0.295)
Non-elective reference cost index	-0.152 (0.032)**	-0.139 (0.050)*	-0.152 (0.033)**	-0.082 (0.257)	-0.101 (0.000)***
Reference cost index for hip replacement	-0.069 (0.397)	-0.068 (0.396)	0.040 (0.503)	0.025 (0.645)	0.007 (0.609)

Residuals are computed estimating a model, by OLS, which controls for population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. The statistic in year 2012-13 and 2013-14 is therefore omitted. The statistic for all years is obtained using data from 2008-09 to 2011-12.

p-values (in parentheses) are calculated assuming a normal distribution of the indicator; *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A9 – Likelihood Ratio test to compare spatial lag and SAC model

Indicator	Cross-Section				Panel
	2010-11	2011-12	2012-13	2013-14	FE
Quality					
Clinical					
Summary Hospital-level Mortality Indicator	(0.687)	(0.560)	(0.419)	(0.556)	(0.363)
Hip fracture mortality rate	(0.348)	(0.779)	(0.078)*	(0.189)	(0.333)
Stroke mortality rate	(0.201)	(0.570)	(0.524)	(0.795)	(0.766)
Emergency readmission rate	(0.659)	(0.087)*			(0.816)
Patient reported					
Average health change after hip replacement	(0.491)	(0.831)	(0.671)	(0.408)	(0.643)
Overall patient satisfaction	(0.045)**	(0.550)	(0.509)	(0.397)	(0.726)
Patient satisfaction on hospital cleanliness	(0.968)	(0.580)	(0.431)	(0.586)	(0.793)
Patient satisfaction on decision involvement	(0.453)	(0.790)	(0.353)	(0.705)	(0.815)
Efficiency					
Bed occupancy rate	(0.200)	(0.895)	(0.184)	(0.989)	(0.616)
Rate of cancelled elective operations	(0.015)**	(0.705)	(0.035)**	(0.075)*	(0.001)***
Reference cost index	(0.201)	(0.151)	(0.428)	(0.338)	(0.928)
Elective reference cost index	(0.241)	(0.504)	(0.337)	(0.231)	(0.020)**
Non-elective reference cost index	(0.121)	(0.033)**	(0.075)*	(0.313)	(0.324)
Reference cost index for hip replacement	(0.180)	(0.632)	(0.850)	(0.675)	(0.995)
Null hypothesis: the spatial lag model is nested in the SAC model					
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1					

Table A10 – Spatial lag model for the quality indicators allowing for spatially lagged efficiency

Variable		Quality indicators							
		SHMI	Hip fract. mortality	Stroke mortality	Readm.	Health change hip repl.	Overall satisf.	Satisf. on cleanliness	Satisf. on involvem.
Spatial lag	2010-11	0.212 (0.043)**	0.016 (0.891)	-0.156 (0.156)	0.203 (0.047)**	-0.006 (0.958)	0.047 (0.568)	-0.016 (0.873)	0.035 (0.719)
Spatially lagged bed occupancy rate	2010-11	0.281 (0.142)	-0.044 (0.372)	0.161 (0.014)**	0.022 (0.411)	-0.001 (0.341)	-0.078 (0.102)	-0.004 (0.923)	0.006 (0.902)
Spatially lagged reference cost index	2010-11	-0.154 (0.420)	0.014 (0.775)	0.002 (0.972)	0.033 (0.132)	-0.001 (0.060)*	0.015 (0.745)	-0.067 (0.116)	0.031 (0.502)
Spatial lag	2011-12	0.159 (0.130)	0.094 (0.403)	-0.176 (0.132)	0.117 (0.254)	-0.064 (0.606)	0.061 (0.460)	-0.054 (0.565)	0.075 (0.405)
Spatially lagged bed occupancy rate	2011-12	0.495 (0.019)**	0.026 (0.632)	0.038 (0.698)	0.051 (0.005)***	-0.001 (0.133)	-0.069 (0.171)	-0.079 (0.071)*	-0.051 (0.323)
Spatially lagged reference cost index	2011-12	-0.070 (0.723)	-0.067 (0.196)	0.017 (0.846)	0.017 (0.438)	-0.001 (0.383)	-0.037 (0.444)	-0.080 (0.058)*	-0.090 (0.070)*
Spatial lag	2012-13	0.098 (0.328)	-0.199 (0.085)*	-0.189 (0.097)*	0.091 (0.327)	-0.157 (0.207)	0.003 (0.971)	-0.082 (0.371)	-0.130 (0.163)
Spatially lagged bed occupancy rate	2012-13	0.551 (0.004)***	0.0004 (0.995)	-0.057 (0.521)	0.018 (0.351)	0.000001 (0.999)	-0.063 (0.064)*	-0.048 (0.222)	-0.102 (0.028)**
Spatially lagged reference cost index	2012-13	0.040 (0.812)	-0.023 (0.682)	-0.137 (0.080)*	0.008 (0.625)	-0.0004 (0.482)	-0.060 (0.142)	-0.089 (0.065)*	-0.134 (0.015)**
Spatial lag	20113-14	0.156 (0.164)	-0.205 (0.083)*	-0.305 (0.013)**	0.092 (0.351)	-0.195 (0.082)*	0.084 (0.349)	0.044 (0.624)	0.029 (0.761)
Spatially lagged bed occupancy rate	20113-14	0.180 (0.352)	0.024 (0.590)	0.106 (0.212)	0.021 (0.362)	-0.001 (0.371)	-0.039 (0.312)	-0.072 (0.080)*	-0.095 (0.064)*
Spatially lagged reference cost index	20113-14	0.160 (0.378)	-0.040 (0.346)	0.059 (0.465)	-0.036 (0.092)*	-0.0005 (0.367)	-0.026 (0.550)	-0.081 (0.084)*	-0.061 (0.296)
Spatial lag	FE	0.170 (0.001)***	-0.040 (0.468)	-0.060 (0.279)	0.065 (0.233)	-0.039 (0.505)	0.084 (0.113)	-0.069 (0.218)	-0.032 (0.552)
Spatially lagged bed occupancy rate	FE	-0.051 (0.626)	0.004 (0.924)	-0.047 (0.456)	0.014 (0.082)*	-0.001 (0.225)	-0.060 (0.109)	-0.027 (0.347)	-0.071 (0.089)*
Spatially lagged reference cost index	FE	0.049 (0.563)	-0.008 (0.816)	-0.116 (0.028)**	0.009 (0.463)	0.0003 (0.515)	-0.006 (0.856)	-0.020 (0.431)	0.021 (0.562)
Spatial lag	RE	0.181 (0.000)***	-0.021 (0.710)	-0.057 (0.316)	0.114 (0.028)**	-0.035 (0.557)	0.092 (0.052)*	-0.045 (0.382)	-0.001 (0.986)
Spatially lagged bed occupancy rate	RE	0.091 (0.374)	0.015 (0.622)	0.004 (0.933)	0.018 (0.044)**	-0.001 (0.093)*	-0.060 (0.025)**	-0.043 (0.083)*	-0.067 (0.031)**
Spatially lagged reference cost index	RE	0.051 (0.544)	-0.007 (0.791)	-0.070 (0.116)	0.004 (0.713)	-0.001 (0.092)*	-0.032 (0.223)	-0.044 (0.064)*	-0.035 (0.251)
Control variables are identical to those in the main regression									
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1									

Table A11 – Spatial lag model for the efficiency indicators allowing for spatially lagged quality

Variable		Efficiency indicators					
		Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	Unit cost of hip repl.
Spatial lag	2010-11	-0.054 (0.619)	0.084 (0.424)	-0.029 (0.806)	0.016 (0.886)	-0.064 (0.572)	-0.122 (0.292)
Spatially lagged SHMI	2010-11	-0.021 (0.817)	-0.002 (0.773)	-0.256 (0.030)**	-0.494 (0.032)**	-0.615 (0.004)***	0.00002 (0.548)
Spatially lagged overall patient satisfaction	2010-11	-0.639 (0.026)**	0.006 (0.785)	-0.573 (0.090)*	-0.966 (0.172)	-1.582 (0.014)**	0.0001 (0.221)
Spatial lag	2011-12	-0.114 (0.333)	-0.024 (0.839)	-0.038 (0.742)	0.034 (0.757)	-0.081 (0.468)	-0.230 (0.039)**
Spatially lagged SHMI	2011-12	-0.113 (0.248)	-0.005 (0.415)	-0.157 (0.169)	-0.540 (0.006)***	-0.415 (0.037)**	0.00003 (0.239)
Spatially lagged overall patient satisfaction	2011-12	-1.083 (0.000)***	0.003 (0.866)	-0.185 (0.566)	-0.627 (0.261)	-0.512 (0.357)	0.00009 (0.215)
Spatial lag	2012-13	-0.097 (0.401)	0.125 (0.246)	-0.124 (0.286)	0.030 (0.787)	-0.145 (0.189)	-0.011 (0.925)
Spatially lagged SHMI	2012-13	0.037 (0.705)	-0.004 (0.574)	-0.088 (0.478)	-0.257 (0.183)	-0.367 (0.047)**	0.00003 (0.199)
Spatially lagged overall patient satisfaction	2012-13	-0.427 (0.242)	0.041 (0.120)	-0.259 (0.579)	-1.094 (0.131)	-0.714 (0.308)	-0.00010 (0.325)
Spatial lag	20113-14	0.049 (0.641)	0.040 (0.713)	0.060 (0.609)	-0.049 (0.682)	-0.018 (0.884)	0.060 (0.613)
Spatially lagged SHMI	20113-14	-0.203 (0.049)**	-0.009 (0.209)	-0.053 (0.717)	-0.274 (0.248)	-0.395 (0.075)*	-0.00001 (0.691)
Spatially lagged overall patient satisfaction	20113-14	-0.290 (0.331)	-0.026 (0.199)	0.035 (0.933)	-0.112 (0.872)	-0.299 (0.635)	0.00004 (0.591)
Spatial lag	FE	-0.090 (0.136)	0.018 (0.736)	0.029 (0.607)	0.046 (0.430)	-0.076 (0.179)	-0.095 (0.091)*
Spatially lagged SHMI	FE	0.003 (0.954)	0.010 (0.017)**	0.077 (0.233)	-0.051 (0.685)	0.077 (0.537)	0.00003 (0.115)
Spatially lagged overall patient satisfaction	FE	-0.280 (0.064)*	-0.006 (0.560)	0.050 (0.758)	0.403 (0.214)	0.434 (0.168)	0.00003 (0.552)
Spatial lag	RE	-0.053 (0.367)	0.050 (0.353)	0.090 (0.103)	0.059 (0.297)	0.025 (0.647)	-0.069 (0.220)
Spatially lagged SHMI	RE	-0.031 (0.561)	0.003 (0.485)	0.024 (0.713)	-0.183 (0.116)	-0.171 (0.150)	0.00002 (0.203)
Spatially lagged overall patient satisfaction	RE	-0.512 (0.001)***	-0.001 (0.929)	-0.144 (0.403)	-0.025 (0.937)	-0.364 (0.257)	0.00003 (0.522)
Control variables are identical to those in the main regression							
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1							

Table A12 – ML estimates of the spatial lag when hospitals compete within a radius of 60 km

Indicator	Monop	Cross-Section				Panel	
		2010-11	2011-12	2012-13	2013-14	FE	RE
Quality							
Clinical							
Summary Hospital-level Mortality Indicator	1	0.288 (0.018)**	0.183 (0.144)	0.199 (0.087)*	0.186 (0.166)	0.197 (0.008)***	0.222 (0.001)***
Hip fracture mortality rate	1	-0.318 (0.048)**	-0.125 (0.509)	-0.279 (0.093)*	-0.117 (0.508)	-0.113 (0.187)	-0.097 (0.247)
Stroke mortality rate	1	-0.050 (0.738)	-0.236 (0.186)	-0.196 (0.290)	-0.210 (0.300)	-0.069 (0.403)	-0.005 (0.951)
Emergency readmission rate	1	0.105 (0.428)	0.159 (0.211)			0.085 (0.227)	0.156 (0.022)**
Patient reported							
Average health change after hip replacement	1	0.009 (0.962)	-0.150 (0.419)	-0.353 (0.034)**	-0.273 (0.153)	-0.129 (0.174)	-0.067 (0.456)
Overall patient satisfaction	1	0.227 (0.034)**	0.148 (0.167)	0.168 (0.126)	0.320 (0.003)***	0.240 (0.000)***	0.248 (0.000)***
Patient satisfaction on hospital cleanliness	1	0.175 (0.172)	0.113 (0.378)	0.084 (0.524)	0.231 (0.055)*	0.091 (0.230)	0.124 (0.081)*
Patient satisfaction on decision involvement	1	0.174 (0.136)	0.143 (0.255)	0.049 (0.703)	0.237 (0.059)*	0.050 (0.516)	0.125 (0.071)*
Efficiency							
Bed occupancy rate	1	0.020 (0.892)	-0.003 (0.986)	-0.251 (0.069)*	-0.067 (0.636)	-0.001 (0.993)	0.002 (0.976)
Rate of cancelled elective operations	1	0.195 (0.153)	0.005 (0.975)	0.094 (0.511)	0.107 (0.441)	0.128 (0.080)*	0.141 (0.046)**
Reference cost index	1	-0.081 (0.504)	-0.038 (0.744)	-0.066 (0.634)	0.091 (0.459)	-0.013 (0.866)	0.052 (0.452)
Elective reference cost index	1	0.103 (0.406)	-0.027 (0.828)	-0.042 (0.750)	0.186 (0.171)	-0.126 (0.066)*	-0.043 (0.527)
Non-elective reference cost index	1	-0.054 (0.705)	0.127 (0.306)	-0.152 (0.305)	-0.101 (0.479)	-0.107 (0.184)	0.008 (0.909)
Reference cost index for hip replacement	1	0.050 (0.737)	0.057 (0.704)	0.208 (0.170)	0.076 (0.636)	-0.080 (0.374)	0.031 (0.706)

Monop = monopolist hospitals (hospitals without rivals within a radius of 60 km), which are removed from the sample

Each cross-sectional regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. Cross-sectional estimates in year 2012-13 and 2013-14 are therefore omitted. Panel estimates are obtained using data from 2008-09 to 2011-12. In addition, data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value <0.05, * p-value <0.1

Table A13 – ML estimates of the spatial lag when hospitals compete within a radius of 90 km

Indicator	Monop	Cross-Section				Panel	
		2010-11	2011-12	2012-13	2013-14	FE	RE
Quality							
Clinical							
Summary Hospital-level Mortality Indicator	0	0.294 (0.057)*	0.255 (0.098)*	0.148 (0.304)	0.047 (0.771)	0.270 (0.005)***	0.264 (0.002)***
Hip fracture mortality rate	1	-0.310 (0.197)	-0.265 (0.315)	-0.252 (0.309)	0.012 (0.958)	-0.127 (0.283)	-0.067 (0.558)
Stroke mortality rate	0	-0.145 (0.439)	-0.129 (0.587)	-0.214 (0.268)	-0.463 (0.098)*	-0.061 (0.571)	0.032 (0.755)
Emergency readmission rate	0	0.102 (0.499)	0.147 (0.326)			0.082 (0.326)	0.160 (0.045)**
Patient reported							
Average health change after hip replacement	0	-0.254 (0.243)	-0.347 (0.182)	-0.289 (0.212)	-0.323 (0.190)	-0.235 (0.061)*	-0.149 (0.205)
Overall patient satisfaction	0	0.235 (0.061)*	0.230 (0.055)*	0.208 (0.104)	0.349 (0.007)***	0.369 (0.000)***	0.333 (0.000)***
Patient satisfaction on hospital cleanliness	0	0.058 (0.715)	0.033 (0.831)	0.028 (0.857)	0.164 (0.266)	-0.003 (0.975)	0.042 (0.651)
Patient satisfaction on decision involvement	0	0.164 (0.242)	0.181 (0.211)	0.038 (0.805)	0.292 (0.047)**	0.078 (0.404)	0.154 (0.060)*
Efficiency							
Bed occupancy rate	0	0.114 (0.518)	-0.057 (0.770)	-0.381 (0.029)**	-0.023 (0.897)	0.018 (0.843)	0.026 (0.769)
Rate of cancelled elective operations	0	0.201 (0.199)	0.006 (0.975)	0.057 (0.747)	0.072 (0.674)	0.117 (0.213)	0.137 (0.122)
Reference cost index	0	-0.064 (0.620)	-0.082 (0.508)	0.058 (0.708)	0.169 (0.200)	-0.037 (0.687)	0.055 (0.489)
Elective reference cost index	0	0.113 (0.431)	-0.123 (0.390)	-0.005 (0.973)	0.177 (0.236)	-0.174 (0.031)**	-0.072 (0.353)
Non-elective reference cost index	0	-0.017 (0.910)	0.178 (0.175)	-0.026 (0.879)	-0.123 (0.457)	-0.147 (0.138)	0.034 (0.684)
Reference cost index for hip replacement	0	0.053 (0.767)	0.090 (0.629)	0.204 (0.281)	0.003 (0.990)	-0.144 (0.235)	0.012 (0.913)

Monop = monopolist hospitals (hospitals without rivals within a radius of 90 km), which are removed from the sample

Each cross-sectional regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. Cross-sectional estimates in year 2012-13 and 2013-14 are therefore omitted. Panel estimates are obtained using data from 2008-09 to 2011-12. In addition, data on hospital staff are available from 2010-11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value <0.01, ** p-value <0.05, * p-value <0.1

Table A14 – First-stage estimates on the instrument and F statistic using quality indicators

	Regressors		SHMI	Hip fract. mortality	Emerg. readm.	Overall satisf.	Satisf. on cleanliness	Satisf. on involvem.
IV 1	I stage coefficient on the instrument	2013-14	0.393 (0.000)***	0.320 (0.000)***	0.796 (0.000)***	0.600 (0.000)***	0.880 (0.000)***	0.784 (0.000)***
	I stage F (Cragg-Donald) statistic		39.70	14.30	101.60	159.30	234.30	145.80
IV 2	I stage coefficient on the instrument	2010-11	-4.629 (0.000)***		0.604 (0.000)***	-2.583 (0.000)***	-1.616 (0.000)***	-1.665 (0.000)***
	I stage F (Cragg-Donald) statistic		14.96		45.24	118.70	65.30	44.70
	I stage coefficient on the instrument	2011-12	-3.964 (0.000)***		0.514 (0.000)***	-2.658 (0.000)***	-1.495 (0.000)***	-1.845 (0.000)***
	I stage F (Cragg-Donald) statistic		20.33		22.85	107.20	49.00	49.60
	I stage coefficient on the instrument	2012-13	-2.224 (0.004)***			-1.844 (0.000)***	-1.638 (0.000)***	-1.876 (0.000)***
	I stage F (Cragg-Donald) statistic		7.49			85.10	65.40	51.50
	I stage coefficient on the instrument	2013-14	-1.972 (0.002)***			-1.902 (0.000)***	-1.657 (0.000)***	-1.985 (0.000)***
	I stage F (Cragg-Donald) statistic		8.69			88.00	54.70	62.80

IV 1 = IV strategy using the three-year lagged spatial lag of the dependent variable as instrument (WY_{t-3}).

IV 2 = IV strategy using a spatially lagged cost shifter as instrument (WZ). The instruments for the IV 2 strategy are: (spatially) lagged proportion of consultants for the lagged SHMI mortality rate; lagged proportion of junior doctors in training for lagged emergency readmission rate, lagged overall patient satisfaction, lagged patient satisfaction on hospital cleanliness, and lagged patient satisfaction on decision involvement.

Stock-Yogo 10% maximal IV size critical value = 16.38; Stock-Yogo 15% maximal IV size critical value = 8.96; Stock-Yogo 20% maximal IV size critical value = 6.66; Stock-Yogo 25% maximal IV size critical value = 5.53

Each regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. Control variables are included in the first stage of the 2SLS estimator.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011-12. For IV 1, the estimate refers to the latest available year (2011-12) and not to 2013-14. For IV 2, estimates in year 2012-13 and 2013-14 are omitted.

For stroke mortality and average health change after hip replacement, IV 1 and IV 2's estimates are omitted because of the absence of valid instruments. Similarly, IV 2's estimates are omitted for hip fracture mortality.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A15 – First-stage estimates on the instrument and F statistic using efficiency indicators

	Regressors		Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	RCI for hip repl.
IV 1	I stage coefficient on the instrument	2013-14	0.616 (0.000)***	0.480 (0.000)***	0.704 (0.000)***	0.380 (0.000)***	0.483 (0.000)***	0.291 (0.000)***
	I stage F (Cragg-Donald) statistic		113.70	35.60	177.60	53.30	51.30	23.45
IV 2	I stage coefficient on the instrument	2010-11	6.160 (0.000)***	0.074 (0.400)	-2.328 (0.000)***	-3.949 (0.000)***	-4.924 (0.000)***	
	I stage F (Cragg-Donald) statistic		18.12	0.63	14.30	11.37	22.73	
	I stage coefficient on the instrument	2011-12	4.387 (0.000)***	0.119 (0.064)*	-3.124 (0.000)***	-4.305 (0.000)***	-6.347 (0.000)***	
	I stage F (Cragg-Donald) statistic		12.77	3.04	29.54	16.18	36.64	
	I stage coefficient on the instrument	2012-13	5.383 (0.000)***	0.362 (0.000)***	-1.850 (0.001)***	-3.292 (0.000)***	-3.380 (0.000)***	
	I stage F (Cragg-Donald) statistic		11.59	13.03	10.30	12.39	11.81	
	I stage coefficient on the instrument	2013-14	4.267 (0.000)***	0.347 (0.000)***	-1.907 (0.000)***	-1.456 (0.069)*	-2.993 (0.001)***	
	I stage F (Cragg-Donald) statistic		11.12	17.67	11.14	2.95	9.72	

IV 1 = IV strategy using the three-year lagged spatial lag of the dependent variable as instrument (WY_{t-3}).

IV 2 = IV strategy using a spatially lagged cost shifter as instrument (*WZ*). The instruments for the IV 2 strategy are: spatially lagged proportion of consultants for lagged reference cost index, lagged elective and non-elective reference cost index; lagged number of managers for lagged bed occupancy rate and lagged rate of cancelled elective operations.

Stock-Yogo 10% maximal IV size critical value = 16.38; Stock-Yogo 15% maximal IV size critical value = 8.96; Stock-Yogo 20% maximal IV size critical value = 6.66; Stock-Yogo 25% maximal IV size critical value = 5.53

Each regression controls for: population density, proportion of elderly individuals, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. Control variables are included in the first stage of the 2SLS estimator.

IV 2's estimates are omitted for the RCI for hip replacement because of the absence of a valid instrument.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A16 – F-test to study the exclusion restriction assumption of *WZ*

Indicator	Instrument	F-test on *WZ* in main regression			
		2010-11	2011-12	2012-13	2013-14
Quality					
Clinical					
Summary Hospital-level Mortality Indicator	Lagged proportion of consultants	(0.064)*	(0.175)	(0.739)	(0.490)
Emergency readmission rate	Lagged prop. of junior doctors in training	(0.149)	(0.240)		
Patient reported					
Overall patient satisfaction	Lagged prop. of junior doctors in training	(0.695)	(0.723)	(0.698)	(0.111)
Patient satisfaction on hospital cleanliness	Lagged prop. of junior doctors in training	(0.322)	(0.588)	(0.946)	(0.910)
Patient satisfaction on decision involvement	Lagged prop. of junior doctors in training	(0.024)**	(0.173)	(0.721)	(0.436)
Efficiency					
Bed occupancy rate	Lagged number of managers	(0.617)	(0.946)	(0.542)	(0.594)
Rate of cancelled elective operations	Lagged number of managers	(0.739)	(0.598)	(0.498)	(0.204)
Reference cost index	Lagged prop. of junior doctors in training	(0.402)	(0.666)	(0.734)	(0.3)
Elective RCI	Lagged prop. of junior doctors in training	(0.016)	(0.086)	(0.141)	(0.097)
Non-elective RCI	Lagged prop. of junior doctors in training	(0.883)	(0.091)	(0.277)	(0.763)

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A17 – Comparison of the results in Gravelle et al. (2014b) and in our study

Indicator		GSS (2014)	Our study			
		2009-10	2010-11	2011-12	2012-13	2013-14
Overall mortality	(1)	0.276 (0.004)***	0.377 (0.000)***	0.260 (0.008)***	0.162 (0.106)	0.241 (0.027)**
	(2)	0.234 (0.019)**	0.314 (0.001)***	0.214 (0.036)**	0.105 (0.304)	0.173 (0.119)
Hip fracture mortality rate	(1)	0.028 (0.807)	0.118 (0.286)	0.103 (0.374)	-0.121 (0.283)	-0.105 (0.370)
	(2)	-0.066 (0.580)	-0.019 (0.868)	0.093 (0.422)	-0.218 (0.054)*	-0.203 (0.087)*
Stroke mortality rate	(1)	0.179 (0.100)*	-0.037 (0.748)	-0.172 (0.143)	-0.123 (0.284)	-0.291 (0.015)**
	(2)	0.147 (0.189)	-0.127 (0.265)	-0.203 (0.083)*	-0.163 (0.162)	-0.316 (0.009)***
Patient satisfaction on hospital cleanliness	(1)	0.179 (0.070)*	-0.003 (0.976)	-0.015 (0.869)	-0.060 (0.538)	0.045 (0.622)
	(2)	0.171 (0.077)*	-0.045 (0.633)	-0.030 (0.740)	-0.111 (0.248)	0.009 (0.918)
Patient satisfaction on decision involvement	(1)	0.245 (0.012)**	0.092 (0.272)	0.068 (0.407)	-0.022 (0.792)	0.060 (0.504)
	(2)	0.167 (0.102)	0.005 (0.953)	-0.038 (0.649)	-0.087 (0.317)	-0.031 (0.736)
GSS (2014) = Gravelle at al. (2014b).						
Specification (1) controls for: number of rivals, teaching trusts, foundation trusts, specialist hospitals, number of patients, market forces factor, population density, London trusts.						
Specification (2) controls for all covariates in (1) and for: proportion of elderly individuals, proportion of individuals employed and looking for a job, proportion of individuals with a degree, proportion of households with property house, proportion of individuals with a degree, proportion of individuals in good and very good health.						
The specialist dummy is omitted if the quality indicator's sample does not include specialist hospitals, i.e. for all indicators included in Gravelle, Santos, and Siciliani (2014) and for SHMI, hip fracture and stroke mortality rate.						
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1						